THE VENTILATION OF COAL MINES,

BY

W. FAIRLEY, M.E., F.S.S.,

AND

GEO. J. ANDRÉ.

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PREFACE.

THE object of the following articles is to give to the practical miner as clear an idea as possible of the general principles of mine ventilation. The subject is one of the most important that can engage the attention of the mining engineer, and is one that should be well understood by all who are engaged underground. It is to be feared that this is far from being the case—that great ignorance still prevails in mining quarters on the subject, and that there is much need of a dissemination of information on the art of ventilating engineering.

The fact that 586 lives were lost in 1880 by explosions of fire damp emphasizes the remarks of the writer as to the

importance of the question, and a consideration of the circumstances under which some of those explosions occurred force upon him the opinion that much has yet to be learned by many officials who are treated as competent.

Every ordinary miner should have a knowledge of the subject, because—in fiery mines especially—the safety of the whole number depends upon the individual action of each man employed.

The writers have attempted to explain as much as possible, by the working out of examples arithmetically, the various principles taken into consideration.

To those who are masters of the subject, some of the explanations given may be considered unnecessary; their reply to this is, they have not written for them, but for those who do not understand it; and, for the sake of those practical men who are anxious to grapple with the question,

they have treated it as much as possible according to the simple rules of arithmetic. The most that will be required of the student in working out the examples given is a practical acquaintance with the manner of extracting square and cube roots.

The cause of motion in air has been explained in the first section, where it has been shown arithmetically that pressure may be expressed either by feet of air column, inches of water gauge, or pounds per square foot.

The friction of air has then been dealt with, and several new formulæ have been given, which will be found useful in working out practical examples.

An explanation of splitting has been entered into, and the difference between equal and unequal splitting has been explained.

Ascensional ventilation is a matter

which deserves the attention of all mining engineers, and no doubt a proper knowledge of this art would enable ventilating engineering to be conducted practically in a much better and far more economical manner than it usually is.

Next, it has been considered necessary to draw particular attention to *Velocity*, and to endeavor to fix some medium as the speed at which air should travel. Many practical men think the pit is well aired if the current is traveling at a high speed, but there is a medium in this as in other things.

The co-efficient of friction, referred to especially, depends on the nature of the sides of the channel through which the air passes, and even in the same pit the co-efficient may be different, according to the rubbing surfaces of the roads; the smoother the sides the less the friction, and roads formed with brick work have

only about one-half the friction of ordinary underground roads.

The writers do not profess to have exhausted the subject, but they hope by thus drawing attention to it that they will be the means of increasing amongst miners a knowledge of it.

There are one or two other points in the subject which they would like to have gone into, but circumstances do not permit them to go further into the matter at present.

Their desire in compiling these articles has been to make them of utility to practical men, and they will be glad to know if they have in any degree succeeded in their object.

THE VENTILATION OF COAL MINES.

By W. Fairley, M. E.

1. Motion in air is caused by pressure or difference of pressure—pressure is obtained by difference in density—and the movement is in the direction from the heavier to the lighter air. Pressure, or difference of pressure, as regards air circulating in mines, may be obtained either by the application of heat, as by a furnace, or by exhausting the air mechanically from the workings by a fan; it is no matter which of these means is applied to procure difference of pressure, the result will be the same with the same difference of pressure, however obtained.

2. If there are two shafts of equal depth, having a passage at the bottom connecting them, and the temperature and density of the air are the same in each shaft, then, as there is nothing to

destroy the equilibrium of pressure, the air will remain stagnant.

3. If by some artificial means, as by a furnace, the temperature of one of the shafts is raised above that of the other, or there is an exudation of the lighter gases, then the air in that shaft will be less dense, and the air will move in that direction from the colder shaft—the heavier column descending and forcing up the lighter one with a velocity proportionate to the pressure caused by the difference of density.

4. If the tops of the two shafts were not on the same level, the atmospheric pressure would be the same at the same level above the surface, and the extra head of air above the shorter shaft, forming part of the outward atmosphere, would have the same effect as if it were contained in a shaft which rose to the same height. In this case, if the external temperature were lower than the temperature of the strata in which the shafts and the passage were made, the circulation of the air would be down the shorter shaft and up the longer

one. On the other hand, if the exterior temperature be higher than that of the shafts and strata, the shorter shaft will be the upcast.

5. The *motive column* is a head of air of such a height that it will equal the difference of the weight between the air in the downcast and upcast shafts; and it is found by calculation from this rule:

$$M = D \times \frac{t_2 - t_1}{459 + t_1}$$

M=motive column, D=depth of upcast in feet, t_1 and t_2 represent the temperatures of the downcast and upcast shafts respectively.

6. The motive column is really a measure of the pressure in force producing the ventilation, and if it is required to express it in pounds per square foot it may be calculated by multiplying the depth of the shaft in feet by the weight of one foot of air at the average temperature of the air in the shaft. Do this for each shaft and deduct the one from the other, the difference will be the pressure producing the ventilation. The follow-

ing table gives the weight of a foot of air at various temperatures, and may be found useful to the student for this and other purposes.

TABLE showing the weight of a cubic foot of air in decimals of a pound avoirdupois, at different temperatures, calculated from the formula

$$W = \frac{1.32529 \times 30}{459+t} = \frac{39.7587}{459+t}$$

Temperature t.	Weight in decimals of a lb.	Temperature t.	Weight in decimals of a lb.
32	.0809749	120	.0686678
35	.0804831	125	.0680799
40	.0796767	130	.0675020
45	0788863	135	.0669338
50	.0781113	140	.0663751
55	.0773515	145	.0658256
60	.0766063	150	0652852
62	.0763122	155	.0647535
65	.0758753	160	.0642305
70	.0751582	165	.0637158
75	.0744544	170	.0632093
80	.0737638	175	.0627108
85	.0730858	180	.0622201
90	.0724202	185	.0617371
95	.0717666	190	.0612614
100	.0711246	195	.0607931
105	.0704941	200	.0603318
110	0698746	205	.0598775
115	.0692660	212	.0592529

7. The force which operates in putting air in motion may likewise be expressed by saying it is equal to so much water gauge, generally expressed in inches and decimals. With air and water at a temperature of 62°, the following rules will apply for converting the pressure into different terms:

Water gauge in inches $\times$ 5.196 = pounds per square foot.

Pounds per square foot divided by .0763122 = length of motive column in feet.

8. The velocity of air without resistance is the same that a body would attain in falling the height of the motive column, so that if there is a difference of pressure equal to 34 ft. of air column, the theoretical velocity of the air would be about 47 ft. per second, because a falling body, under the force of gravity, would attain a velocity of 8.025 times the square root of 34, or 47 nearly. It will thus be seen that were it not for the resistances encountered by air in passing along underground roads, a very small pressure

would suffice to produce a great velocity. To show the theoretical velocity due to various pressures or motive columns, the table following has been constructed; from this we see that with 2 in. of water guage, a very common pressure in colliery ventilation, a velocity of 93 ft. per second would be attained, but as air is retarded in its movement by rubbing against the sides of the channels, nothing like the theoretical velocity is reached in practice. The table shows likewise the pressure variously in pounds per square foot, inches of water gauge and feet of air column.

9. In practice from ten to twenty times as much pressure is required to give that momentum to the air which would suffice for the final velocity, on account of the friction air meets with in rubbing against the sides of the airways in passing round the underground workings.

10. If the whole friction of a mine be measured by 2.18 in. of water gauge, and the final velocity of the air in the upcast is 30 ft. per second—a common enough

TABLE SHOWING THE AMOUNT OF MOTIVE COLUMN OF AIR AND INCHES OF WATER GAUGE NECESSARY TO PRODUCE THE THEORETICAL FINAL VELOCITY IN UP-CAST SHAFTS, WITH AIR AT DIFFERENT TEMPERATURES.

Velocity in feet per second.	Motive column of air.	Water gauge in decimals of an inch at the following temperatures.								
$A=8.025\sqrt{B}$	$B=\frac{A^2}{64.4}$	$C=\frac{\frac{1.32529\times 30}{459+t}}{5.196}\times B$								
		Degs. 90	Degs. 105	Degs. 120	Degs. 135	Degs. 150	Degs. 165	Degs. 180	Degs. 195	Degs. 210
5	.39	.005	.005	:005	.005	.005	.005	.005	.005	.004
10	1.55	.022	.021	.020	.020	.019	.019	.019	.018	.018
15	3.49	.049	.047	046	.045	.044	.043	.042	.041	040
20	6.21	.087	.084	.082	.080	.078	.076	.074	.073	.071
25	9.70	.135	.132	128	.125	.122	.119	.116	.113	.111
30	13.98	.195	.190	.185	.180	.176	.171	.167	164	.160
35	19.02	.265	.258	.251	.245	.239	.233	.228	.223	.218
40	24.84	.346	.337	.328	.320	.312	.305	.297	.291	.284

TABLE showing the comparative height of water gauge and air column at a temperature of 62 degs. Fahr., with pressure in pounds per square foot and theoretical velocity of air due to this pressure.

NOTE.—Weight of cubic foot of air at 62 degs.=.0763122 lb., and of water =62.355 lb.

Water gauge in inches.	Pressure in pounds per square foot.	Motive column of air in feet.	Velocity of air in feet per second due to motive column.
$A = \frac{B}{5.196}$	$B = \frac{A \times 62.355}{12}$	$C = \frac{B}{.0763122}$	$D = 8.025 \sqrt{C}$
.1	.5196	6.81	21
.2	1.0392	13.62	30
.3	1.5588	20 43	36
.4	2.0784	27.24	42
.5	2.598	34.04	47
.6	3.1176	40.85	51
.7	3.6372	47.66	55
.8	4.1568	54.47	59
.9	4.6764	61.28	63
1.0	5.196	68.09	66
2.0	10.392	136.18	94
3.0	15.588	204.27	115
4.0	20.784	272.36	132
5.0	25.980	340.45	148
6.0	31.176	408.55	162

velocity in furnace shafts—the temperature of which is, say 135°, it will be found by calculation that 2 in. of this pressure is due to friction, the decimal portion only being required to produce the velocity, the water gauge due to final velocity being found thus:

$$\frac{\frac{30^2}{64.4} \times \frac{1.32529 \times 30}{459+t}}{5.196}$$

The table given on page 16 has been prepared to show the height of water gauge required to generate the theoretical final velocities at various temperatures; this deducted from the total height of water gauge gives that which is to be referred to friction.

Example:—The quantity of air passing in an upcast having an area of 140 ft. is 210,000 cubic ft. per minute; the velocity is therefore 25 ft. per second, the temperature is 210°, then the water gauge due to velocity is by the table equal to .111 inch.

THE RESISTANCE OF AIR IN MOVING ALONG UNDERGROUND PASSAGES.

11. All experiments hitherto made with respect to the movement of fluids of every kind in pipes, passages or channels tend to prove that the resistance to the motion of the fluids is in proportion to the length of the passages traversed, to the perimeter of the section of the passages, to the square of the mean velocity of the fluids, and in inverse ratio to the section, or nearly so.

12. The following rules apply to the friction of air in moving along level passages of uniform size:—Let a = area of airways in square feet; h = horse power of ventilation; k = co-efficient of friction; l = length of air channel; o = perimeter of air channel; p = pressure in pounds per square foot; q = quantity of air circulating in cubic feet per minute; s = area in square feet of rubbing surface

exposed to the air; u = units of work, foot pounds or power applied to circulate the air; v = velocity of the air in feet per minute; w=water gauge in inches; then

1.—$a=\frac{ksv^3}{p}=\frac{pa}{p}=\frac{ksv^2q}{u}=\frac{ksv^3}{pv}=$

$$\frac{u}{pv}=\frac{q}{v}=\frac{q}{\sqrt[3]{\frac{u}{ks}}}$$

2.—$h=\frac{u}{33000}=\frac{qp}{33000}$ &c.

3.—$k=\frac{pa}{sv^2}=\frac{u}{sv^3}=\frac{\frac{p}{sv^2}}{a}=\frac{\frac{w5\frac{1}{5}}{sv^2}}{a}$.

4.—$l=\frac{s}{o}$.

5.—$o=\frac{s}{l}$.

6.—$p=\frac{ksv^3}{a}=\frac{u}{q}=5\frac{1}{5}w=\left(\sqrt[3]{\frac{u}{ks}}\right)^2\frac{ks}{a}=$

$$\frac{pa}{a}=\frac{ksv^3}{q}=\frac{u}{av}.$$

7.—$pa=ksv^2=\left(\sqrt[3]{\frac{u}{ks}}\right)^2 ks=\frac{u}{v}$.

8.—$q = va = \frac{u}{p} = \frac{ksv^3}{p} =$

$$\sqrt{\frac{pa}{ks}}a = \sqrt[3]{\frac{u}{ks}}a.$$

9.—$s = \frac{pa}{kv^2} = \frac{u}{kv^3} = \frac{qp}{kv^3} = \frac{vpa}{kv^3} = lo.$

10.—$u = qp = vpa = \frac{ksv^2q}{a} = ksv^3 =$

$$q5\tfrac{1}{5}\ w = h\ 33{,}000.$$

11.—$v = \frac{u}{pa} = \frac{q}{a} = \sqrt[3]{\frac{u}{ks}} = \sqrt[3]{\frac{qp}{ks}} = \sqrt[2]{\frac{pa}{ks}}.$

12.—$v^2 = \frac{pa}{ks} = \left(\sqrt[3]{\frac{u}{ks}}\right)^2.$

13.—$v^3 = \frac{u}{ks} = \frac{qp}{ks} = \frac{vpa}{ks}.$

14.—$w = \frac{\frac{ksv^2}{a}}{5\frac{1}{5}} = \frac{p}{5\frac{1}{5}}.$

13. These formulæ comprise the pressure referable to resistance, but not that necessary for producing velocity; so that they may be looked upon as more correct for long passages than short ones; that is to say, the pressure required for the final velocity becomes a

smaller fractional part of the whole drag as the pit workings extend. In a general way, for the sake of simplicity, the student need not take into account the pressure necessary for velocity; but if he desires to do so, instead of using p let him use $p-p_v$; p_v being the pressure required to generate the final velocity. In this case,

Instead of using $a=\frac{ksv^2}{p}$ substitute $\frac{ksv^2}{p-p_v}$.

Instead of $pa=ksv^2$, use $a(p-p_v)=ksv^2$.

Instead of $p=\frac{ksv^2}{a}$, use $p-p_v=\frac{ksv^2}{a}$, or

$$p=\frac{ksv^2}{a}+p_v.$$

Instead of $s=\frac{pa}{kv^2}$, use $\frac{(p-p_v)a}{kv^2}$.

Instead of $v=\sqrt{\frac{pa}{ks}}$ use $\sqrt[2]{\frac{(p-p_v)a}{ks}}$.

14. The co-efficient that will be used in working out the examples given in the following paragraphs will be that adopted by Mr. Atkinson, viz., .0217 lb. per square foot of area of section for every foot of

rubbing surface and for a velocity in the air of 1,000 ft. per minute; or .0000000217 lb. for a velocity of one foot per minute, or $\frac{1}{46082950}$.

15. The area of a road, if square or rectangular, is found by multiplying the two sides together; thus a road 6 ft. high and 5 ft. wide = 30 ft. area. The perimeter of the same road would be $2 \times 6 + 2 \times 5 = 22$.

16. The rubbing surface is found by multiplying the perimeter by the length; thus a road to continue for 1,000 yards in length, and measuring 6 ft. $\times$ 5 ft. would have a rubbing surface (s) of $(1{,}000 \times 3 \times 22) = 66{,}000$ square feet.

17. The quantity of air in cubic feet per minute is obtained by multiplying the velocity in feet per minute by the area; the horse power is obtained by multiplying the quantity by the pressure and dividing by 33,000.

18. The student must take care to clearly understand the difference between pressure (p) and power (u). Pressure is

the force per square foot producing the ventilation, and power is the quantity passing multiplied by the pressure

19. The co-efficient is found by dividing the pressure by the rubbing surface, multiplied by the velocity squared, divided by the area, or the value of $\frac{sv^2}{a}$ divided in the pressure (p).

20. The resistance is according to the length of the air channel for the same quantity of air, thus, if a mine were extended from 1,000 to 2,000 yards, the resistance would be doubled.

21. The resistance is according to the square of the velocity, and air courses having the same pressure, area and perimeter, but different lengths, will pass quantities in accordance with the reciprocal of the square root of the length, or the square root of the length divided into one. Suppose an air course 200 yards long pass 7,071 cubic feet, the quantities that will pass in air courses of 400 and 600 yards long, with the same pressure, area, and perimeter, will be

5,000, and 4,082 respectively, because $\sqrt{\frac{1}{200}}=.07071$; $\sqrt{\frac{1}{400}}=.05$; $\sqrt{\frac{1}{600}}=$ .04082 and the fact that lq^2 for each airway gives the same result; proves the question.

22. The quantity of air circulating in a mine is according to the square root of the pressure; in furnace ventilation the pressure increases with the depth (provided the difference of temperature between the two shafts be maintained) and the ventilation with the square root of the depth of the upcast, so that by adding a stack of 30 ft. at the top of an upcast 150 fathoms deep the ventilation capabilities would be increased about $\frac{1}{60}$th.

23. If we obtain a certain quantity by a furnace, and another by steam jet or other means, the combined effect will be according to the square root of the square of the one added to the square of the other; for example, if a mine circulates 25,000 cubic feet of air per minute by furnace alone, and 22,000 by steam

jets alone, the quantity of air that will pass with the two acting together will be $\sqrt{25000^2+22000^2}=33,301$.

24. The quantity of air passing is according to the cube root of the power applied, and *vice versa*, the power necessary is according to the cube of the quantity; thus to treble the quantity of air in a mine, the power necessary would be twenty-seven times as much, and if by an expenditure of 70,087 units of work 16,848 cubic feet be obtained, the quantity that would be got by employing 277,045 units would be 26,639, because:

$$\frac{16848\times\sqrt[3]{277045}}{\sqrt[3]{70087}}=26639.$$

25. The quantity of air passing in airways of different areas, other things being equal, is according to the square root of the area multiplied by the area. Thus, the pressure and rubbing surface being the same in each case, the quantity passing in an airway of 30 ft. area, when 20,000 ft. pass in one of 60 ft. area, will be 7,071, because

$$\frac{\sqrt{30}\times 20000}{\sqrt{60}}\times\frac{30}{60}=7,071.$$

26. To make airways of different lengths of such area as to pass an equal quantity with the same pressure, apportion them according to the formula

$$a=\frac{q}{\sqrt{\frac{u}{ks}}}$$

Thus, in a coal mine ventilated by five different splits or air currents:

The first	200	yards	long	and	9 ft.	area.
" second	400	"	"		?	"
" third	600	"	"		?	"
" fourth	800	"	"		?	"
" fifth	1,000	"	"		?	"

The areas of each of these, to pass the same quantities with the same pressure, will be found thus: reckoning the perimeter to be the same in each case, and taking the length in feet as the rubbing surface, and 10,000 cubic feet as the quantity passing in each road, then u

will be found for the first airway by $\left(\frac{ksv^2}{a}\right) \times q = 17{,}860$, and the value of $\sqrt{\frac{u}{ks}}$ in each of the other roads is:

2nd, 881.883,
3rd, 770.400,
4th, 699.955,
5th, 649.780, then:

2.— $\frac{10000}{881.883} = 11.339$ area.

3.— $\frac{10000}{770.400} = 12.980$ "

4.— $\frac{10000}{699.955} = 14.286$ "

5.— $\frac{10000}{649.780} = 15.389$ "

and the correctness of these areas is proved by finding the amount of pressure, p, for the assumed quantity, which ought to be the same in each case as below:

$$\left(p = \frac{ksv^2}{a}\right)$$

$$1.—\frac{.0000000217 \times 600 \times \left(\frac{10000}{9}\right)^2}{9} = 1.786 \text{ lb.}$$

$$2.—\frac{.0000000217 \times 1200 \times \left(\frac{10000}{11.339}\right)^2}{11.339} = 1.786 \text{ lb.}$$

$$3.—\frac{.0000000217 \times 1800 \times \left(\frac{10000}{12.98}\right)^2}{12.98} = 1.785 \text{ lb.}$$

$$4.—\frac{.0000000217 \times 3000 \times \left(\frac{10000}{15.389}\right)^2}{15.389} = 1.785 \text{ lb.}$$

which is sufficiently near. Or, as in this question the quantity (q), the power (u), k and q are all the same, we may cancel these factors in the equation $a = \frac{q}{\sqrt[3]{\frac{u}{ks}}}$ which will then be reduced to $\sqrt[3]{s}$, then the areas will be simply according to the cube root of the rubbing surface (s); and, as in this we consider the length as the rubbing surface, because the peri-

meters are all taken as equal, the result will be according to the cube root of the length, thus:

1. $\sqrt[3]{600} = 8.4343.$
2. $\sqrt[3]{1200} = 10.6269.$
3. $\sqrt[3]{1800} = 12.1644.$
4. $\sqrt[3]{2400} = 13.3884.$
5. $\sqrt[3]{3000} = 14.4222.$

We now say:

	area.	
If 8.4343 : 9 : : 10.6269	=11.339	of 2nd airway,
" 8.4343 : 9 : : 12.1644	=12.980	of 3rd "
" 8.4343 : 9 : : 13.3884	=14.286	of 4th "
" 8.4343 : 9 : : 14.4222	=15.389	of 5th "

which areas are precisely the same as those obtained above.

27. If a continuous undivided road passing one current of air be of various dimensions, for the purposes of calculation it may be reduced to one typical road of uniform size throughout, the length (l') of which may be found by this rule:

$$l' = \frac{a'^3}{o'} \times \frac{s}{a^3}.$$

a'=area of typical road; o' perimeter of same; s and a = rubbing surface and area respectively of the original uneven road at each series of dimensions.

EXAMPLE: The following are the measurements of an airway, and it is desired to calculate the length of a typical road which will measure 6 ft. square uniformly throughout, and that will offer equal resistance to it.

With a road 6 ft. square, $\frac{a'^3}{o'}$ will equal 1,944.

Length l. Feet.	Size.	Area. a. Feet.	Perimeter. o. Feet.	Rubbing surface. $s=lo$. Feet.	Length of typical road $=l'=$ $1944 \times \frac{s}{a^3}$.
700	7×5	35	24	16,800	761.7
300	4×5	20	18	5,400	1312.2
400	8×3	24	22	8,800	1237.5
500	6×5	30	22	11,000	792.
200	4×4	16	16	3,200	1518.6
2,100	←	Length of Original road.	Length of Typical road.	→	5,622.

Thus we see that the length of the new

road would be 5,622, the old one being 2,100 ft.; and this may be proved in the following manner:—Put the quantity of air passing at 10,500 cubic feet per minute, then the pressure (p) for each part of the original road will be found by $\frac{ksv^2}{a}$ = lbs.

Each part of the original road.

$$1.—\ \frac{.0000000217 \times 16800 \times 300^2}{35} = .9374$$

$$2.—\ \frac{.0000000217 \times 5400 \times 525^2}{20} = 1.6148$$

$$3.—\ \frac{.0000000217 \times 8800 \times 437.5^2}{24} = 1.5229$$

$$4.—\ \frac{.0000000217 \times 11000 \times 350^2}{30} = .9747$$

$$5.—\ \frac{.0000000217 \times 3200 \times 656.25^2}{16} = 1.8690$$

Typical road:

$$\frac{.0000000217 \times 134928 \times 291.6666^2}{36} = 6.9188$$

The correctness of the result is shown by the pressure, p, required to pass the same quantity (which is taken at 10,500)

through the typical road, being the same as is required in all the different parts of the original road put together, viz., 6.9188 lbs.

There are one or two useful practical lessons to be learnt from this illustration. In the first place it will be seen that the typical road of 6 ft. square and 5,622 ft. long will offer exactly the same amount of resistance—with the same quantity of air in motion—that is offered by the irregular road, the dimensions of which are expressed in the five series of figures. It is noteworthy that that part of the uneven road measuring 700 ft. long, and 7 ft. by 5 ft., only requires about half the pressure which is necessary to keep in circulation the same amount of air in that portion of the road measuring 200 ft. long, and 4 ft. by 4 ft.; this is of great importance practically, and shows how the ventilating power of mines may be used up and wasted, as indeed, it too often is, by contracted airways.

28. The power required to circulate 10,500 ft. of air through an airway 1,000

yards long and 7 ft. by 5 ft., amounts to 42,182 units per minute, whereas the power required to circulate the same quantity through a road the same length but only 4 ft. square, would amount to 294,368 units per minute. In other words, it would require an engine nearly seven times the power to pass the same quantity through the smaller airway as through the larger one.

29. The relative powers required to pass equal quantities of air through air courses of the same length, but different areas and perimeters (o) will be found by this rule—$o\left(\frac{1}{a}\right)^3$,—and the table below shows the result of this worked out for five different sized airways :

Size of airways.	o	a	$o\left(\frac{1}{a}\right)^3 =$	Relative powers making the road. $6 \times 6 = 1$.
6 × 6	24	36	.0005144	1.
5 × 5	20	25	.0012800	2.29
4 × 4	16	16	.0039062	7.59
3 × 3	12	9	.0164608	32
2 × 2	8	4	.1250000	243.

Thus it will be seen that to pass the same quantity of air through a road 3 ft. square as through one 6 ft. square of the same length will require thirty-two times the power, &c.

30. In a channel or air course of uneven area and perimeter along which the air travels in one current, and which in cal culation must be taken in a series of lengths of uniform size, the proportion of pressure or power that is taken up by each part of the road will be found by this rule $s \frac{\left(\frac{1}{a}\right)^2}{a}$, or $s \left(\frac{1}{a}\right)^3$.

31. The pressure or power required to overcome the friction in passing equal quantities of air through circular airways or shafts is in inverse proportion to the fifth power of their diameters, or direcıly in proportion to $o \left(\frac{1}{a}\right)^3$.

The table on next page shows the relative pressure and powers required to overcome the friction in passing the same

quantities of air through airways or shafts of the given diameters.

By the table it will be seen that 243 times the power will be required to pass the same quantity of air through a shaft

Diameter of shaft or airway.	Rule.	Relative powers for the same quantity.
18	—	1.
16	$\frac{18^5}{16^5} =$	1.80
14	$\frac{18^5}{14^5} =$	3.51
12	$\frac{18^5}{12^5} =$	7.59
10	$\frac{18^5}{10^5} =$	18.89
8	$\frac{18^5}{8^5} =$	57.66
6	$\frac{18^5}{6^5} =$	243.

6 ft. diameter that is required to pass it through an 18 ft. pit, or through airways of these dimensions. The reader will do well to prove this, and he may do so by taking the usual co-efficient, and ascer-

taining the powers necessary for passing, say, 30,000 ft. of air through two airways, say, of 6 ft. and 18 ft. diameter respectively, and each, say, 500 yards long. This will be found by the rule $u = \frac{ksv^2q}{a}$, which for the 6 ft. diameter channel will be:

$$\frac{.0000000217 \times 28274.4 \times 1061.04^2 \times 30000}{28.274} =$$

732,839 units, and for the channel 18 ft. diameter:

$$\frac{.0000000217 \times 84823.2 \times 117.89^2 \times 30000}{254.469} =$$

30,169 units, and $\frac{732839}{3016} = 243$ nearly, which proves the question.

And the quantity of air that will pass in such airways with the same power is in inverse proportion to the cube root of the relative powers; or with the same pressure in inverse proportion to the square root of the relative powers.

THE EFFECT OF SPLITTING THE AIR.

32. In this place it seems desirable to explain what is meant by "splitting the air." Originally it was the usual custom to circulate the air through a mine in one undivided current, down one shaft, around the workings, and up the other shaft, and this plan is still in use in some simple cases. When this one current is divided in the mine into two or more currents, which unite again at or before reaching the upcast, it is said to be split. Splits may be of equal or unequal length and area. The expression "two equal splits" means that the original one current is divided into two currents, each of half the length, but both with the same area as the original one. It must be noted that the phrase "equal splits" is more a mathematical than a practical one, for it may be safely said that to split a current into two, three, or

more equal dimensions is never done practically; it can, however, in some cases be done nearly. After this explanation it will be understood that theoretical splitting will always show a somewhat better result than practical splitting, because, owing to the varied circumstances of the mine, the air cannot always be exactly equally divided, and in practice, as a rule, the aggregate length of the various splits will be somewhat longer than the original one current; or the splitting will take place too far in-bye, or re-unite again too far away from the bottom of the upcast. No one understood this better than the late Mr. Atkinson; hence he says:—"Every principal split of air should commence as near as possible to the bottom of the downcast shaft, and should have a distinct airway to return in."

In the calculations which will be brought forward in this chapter with reference to splitting, it will be on the assumption that the splits take place at the bottom of the downcast, and re-unite

at the bottom of the upcast—in fact, that the splits are equal. Unequal splitting will be taken into consideration in the next section.

Suppose the original air course of the mine to measure 40 ft. area (a), and 120,-000 rubbing surface (s); by splitting into two equal currents we should get two airways each 40 ft. area (a) and 60,-000 rubbing surface; by splitting into three currents we should have three airways, each 40 ft. area and 40,000 rubbing surface; the area, after splitting, being two or three times that of the original airway, according to the number of splits, but the total rubbing surface remaining the same throughout.

It is necessary here to explain further that when this original one current is divided into two equal splits, they may be considered as one current with double the area, but with the same rubbing surface. When divided into three equal splits, these three divisions may be considered as one airway of treble the orig-

inal area, but with the same rubbing surface, in fact, as tabulated below:

		a.	s.
Original current		40	120,000
Two equal splits	1...	40	60.000
	1...	40	60,000
Equal one current		80	120,000
Three equal splits	1...	40	40,000
	1...	40	40.000
	1...	40	40,000
Equal one current		120	120,000

This will be proved arithmetically further on.

33. The benefit derived from splitting depends very much upon the relative rubbing surfaces and the areas of the shafts, as compared with those of the mine, and unless the friction due to the shafts be taken into account when the effect of splitting is calculated, the result will be fallacious.

Were it not for the resistance of the shafts, which, of course, varies with the

quantity of air passing, the result of splitting would be more easily calculated.

34. It may perhaps be better, for the sake of the student, that we should in the first place consider the effect of splitting without taking into account the shaft resistances, so that he may acquaint himself gradually with the process of calculation, and eventually see the difference of the two results.

35. The following example is given for calculation: the quantity of air passing round a mine in one current before splitting is 10,000 cubic feet per minute; the area of the air course is 20 ft., and the rubbing surface is 24,000; what quantity will circulate when the current is split into 2, 3, 4, 5, 6, and 10 equal divisions, the pressure remaining the same?

In the first place the pressure (p) for the one current may be found by the rule $\frac{ksv^2}{a}$, this will be 6.51 lbs. The effect of splitting into 2, 3, &c., divisions, as has been

explained in paragraph 31, is to double, treble, &c., the area, without altering the rubbing surface, and as the quantity is obtained by the rule $\sqrt{\frac{pa}{ks}} \times a$, we use this to find the quantities with the various splits in operation; but as p, k, and s are the same in all these instances, the formula will be reduced to this simple rule, $\sqrt{a} \times a$, and the relative quantities will be according to the square root of the area multiplied by the area, as tabulated below:

No. of splits.	s.	a.	$q = \sqrt{\frac{pa}{ks}} \times a$.	$p = \frac{ksv^2}{a}$
1	24,000	20	10,000	6.51
2	24,000	40	28,284	6.51
3	24,000	60	61,961	6.51
4	24,000	80	80,000	6.51
5	24,000	100	111,803	6.51
6	24,000	120	146,969	6.51
10	24,000	200	316,228	6.51

or the question may be worked out without reference to the actual dimensions of the areas and rubbing surfaces in each

case, further than considering the areas to vary as 1, 2, 3, 4, &c. Then the quantities that will pass will be most simply found thus:—If $\sqrt{1} \times 1$: 10,000 :: $\sqrt{2} \times 2$: =28,284, the quantity with two splits, and if $\sqrt{1} \times 1$: 10,000 :: $\sqrt[2]{10} \times 10$: = 316,228, the quantity with ten splits as above.

An example similar to this is given further on, showing what the result will be after taking into account the shaft resistances.

36. If the power is to remain the same, instead of the pressure, and the original air course passing 10,000 cubic feet per minute, the quantity that will pass in each case of 2, 3, 4, 5, 6, and 10 equal splits will be simply in direct proportion to the area:—1, 10,000; 2, 20,000; 3, 30,000; 4, 40,000; 5, 50,000; 6, 60,000; 10, 100,000. The rule to find the quantity when the power (u) is given being $\sqrt[3]{\frac{u}{ks}} \times a$, but k, s and u being the same in t e case of all the splits, these may be canceled, and the quantities will be di-

rectly according to the area as stated above.

37. There is a great difference between splitting the air and adding an additional air course of the same length and area as the original one; thus, in dividing one current into two equal splits, we get an increase from 10,000 to 20,000 with the same power, but by adding an additional air course the increase will only be from 10,000 to 15,874; this may be worked out as follows:

Take a to equal 36 and s to equal 18,000, then the power is found by the formula $\frac{ksv^2q}{a} = 8371.4$ foot pounds $= u$. With the additional air course "a" and "s" will be doubled, and as the velocity is got by $\sqrt[3]{\frac{u}{ks}}$, we use these figures $\sqrt{\frac{8371.4}{.0000000217 \times 36000}} \times 72$, to get the quantity which is equal to 15,874 cubic feet per minute, or the quantity is according to the reciprocal of the cube root of the rubbing surface multiplied by the

area; as both *s* and *a* are in the proportion of one to two we say,

If $\sqrt[3]{\frac{1}{1}} \times 1 : 10{,}000 :: \sqrt[3]{\frac{1}{2}} \times 2 : = 15{,}874$,

the same as above.

38. So far, we have not taken into account the shaft resistances, but in the next example we will do so.

If there are 10,000 cubic feet of air passing through a mine in one current, the resistances of the shafts at that time being equal to the resistance of the mine, what extra quantity of air will pass through the mine by adding an additional air course, same length and area as the original one, the power remaining the same?

In order to make the resistance of the shafts and mine equal, take the area and rubbing surface of each the same. With the addition of another air course, both the area and rubbing surfaces in the mine are doubled. Proceeding in this way, the results have been obtained as follows:

Divisions of air.		q.	a.	s.	p.	u.
1	Shafts..	10,000	36	18,000	.83714	8371.4
	Mine ...	10,000	36	18,000	.83714	8371.4
	Total...			36,000		16742.8
2	Shafts .	11,694	36	18,000	1.1455	13394.3
	Mine ...	11,694	72	36,000	.28662	3348.5
	Total...					16742.8

Having taken the area of the shaft and mine at 36, and rubbing surface of each at 18,000 with one current, we find that the power required to pass 10,000 ft. through the mine and shafts amounts to 16742.8 foot pounds (u). The value of p is obtained by

$$\frac{\left(\frac{q}{a}\right)^2 \times s \times k,}{a} \text{ and of } u \text{ by } q\,p.$$

Now, in order to apportion the power that will be used up by the shaft and mine after making the additional air course, we put the two air courses of the mine into one, the dimensions of which will be 72 a and 36,000 s; and use the

formula given in paragraph 30, viz., $\left(\frac{1}{a}\right)^3$. By this we find 13394.3 units are required to pass the same quantity of 11,694 cubic feet per minute through the shafts that 3348.5 units will pass through the mine. Or, the power used in the shafts will be found thus:

$$\frac{16742.8 \times 18000 \times \left(\frac{1}{36}\right)^3}{18000 \times \left(\frac{1}{36}\right)^3 + 36000 \times \left(\frac{1}{72}\right)^3} = 13394.3$$

that of the mine thus:

$$\frac{16742.8 \times 36000 \times \left(\frac{1}{72}\right)^3}{18000 \times \left(\frac{1}{36}\right)^3 + 36000 \times \left(\frac{1}{72}\right)^3} = 3348.5$$

Total.................... 16742.8

39. If the resistances of the shafts are half those of the mine when there are five equal splits, and there are 10,000 ft. of air passing in one current before being split at all, the quantities that will pass through the mine with 2, 3, 4, 5, 6, and 10 equal splits are stated in the table on pages 48 and 49, the same ventilating pressure being in operation.

Division of the current.	Relatively.		
	s	a	$p = \dfrac{s\left(\dfrac{1}{a}\right)^2}{a}$
	1.	2.	3.
1 Shafts......	1	10	.001
1 Mine	2	2	.25
			251
2 Shafts.......	1	10	.001
2 Mine	2	4	.03125
			.03225
3 Shafts	1	10	.001
3 Mine	2	6	.009259
			.010259
4 Shafts	1	10	.001
4 Mine	2	8	.00390625
			.00490625
5 Shafts.......	1	10	.001
5 Mine	2	10	.002
			.003
6 Shafts.......	1	10	.001
6 Mine	2	12	.0011574
			.0021574
10 Shafts	1	10	.001
10 Mine... ...	2	20	.00025
			.00125

Actual.			
s.	a.	p.	$q = \sqrt[2]{\frac{pa}{ks}} \times a$
4.	5.	6.	7.
12,000	100	.02604	10,000
24,000	20	6.51	10,000
		6.53604	
12,000	100	.20267	27,898
24,000	40	6.33337	27,898
		6.53604	
12,000	100	.63710	49,463
24,000	60	5.89894	49,463
		6.53604	
12,000	100	1.33219	71,526
24,000	80	5.20385	71,526
		6.53604	
12,000	100	2.17868	91,469
24,000	100	4.35736	91,469
		6.53604	
12,000	100	3.02959	107,863
24,000	120	3.50645	107,863
		6.53604	
12,000	100	5.22883	141,704
24,000	200	1.30721	141,704
		6.53604	

In this table it is shown that, with six equal splits and area taken at 120, and rubbing surface 24,000 the pressure required to pass 107,863 ft. through the mine is 3.50645. Here we have taken the six equal splits as one current, and to show that this one current would be equal to the six splits taken collectively we give the following figures:

	$s.$	$a.$	$p.$	$q.$
6 equal splits =	4000	20	3.50645	$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$

All the splits are reckoned to be divided at the bottom of the downcast, and to re-unite at the bottom of the upcast. They are therefore all to be considered as subject to one common pressure; taking this for each at 3.50645, and using the formula $\sqrt[2]{\frac{pa}{ks}} \times a$, we shall find that each separate split will pass $17,977\frac{1}{6}$ ft.,

and the total quantity in the six splits will be 107,863 ft., and therefore one current having $s = 24{,}000$ and $a = 120$ is equal to six divisions taken together, each of them having $s = 4000$ and $a = 20$.

Here a of shafts has been made to equal 100 and $s = 12{,}000$, and of mine when there are five splits $a = 100$, $s = 24{,}000$, for by these conditions we shall have the resistances of the shafts half those of the mine when there are five equal splits, as desired in the question. In explanation of the figures given under columns s, a, and p "relatively," it may be said that the rubbing surfaces of the shafts and mine are in the proportion of 1 and 2, both in the case of the one current, and all the splits and the areas are in the proportions given in the second column; the third column shows the relative pressure required to pass equal quantities through airways having the conditions given in columns 1 and 2. With reference to the figures in column 6, they are obtained by apportioning them according to their relative press-

ures in the third column; thus, the pressure per foot at work in producing the ventilation is 6.53604 lbs., when 10,000 ft. pass in the one current, the result being got at by working out both for the shafts and mine the rule

$\dfrac{\left(\frac{q}{a}\right)^2 \times s \times k}{a}$; and we say, for example, in

the case of two splits, if .03225 give 6.53604, what will .001 give? and, if .03225 give 6.53604, what will .03125 give? by which we obtain .20267, the pressure required in the shafts, and 6.33337, the pressure required for an equal quantity of air in the mine; and so for the other splits. The quantity in the seventh column is obtained by

$\sqrt[2]{\dfrac{pa}{ks}} \times a$; or the result may be deter-

mined more directly by using the relative pressures obtained in column .3; the quantities will be according to the square root of these, thus:

$$\text{With 2 splits} = \frac{\sqrt{\frac{.001}{.03225}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 27898$$

$$\text{With 3 splits} = \frac{\sqrt{\frac{.001}{.010259}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 49463.$$

$$\text{With 4 splits} = \frac{\sqrt{\frac{.001}{.00490625}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 71526.$$

$$\text{With 5 splits} = \frac{\sqrt{\frac{.001}{.003}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 91469.$$

$$\text{With 6 splits} = \frac{\sqrt{\frac{.001}{.0021574}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 107863.$$

$$\text{With 10 splits} = \frac{\sqrt{\frac{.001}{.00125}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 141704.$$

40. Considering the resistances of the shaft and mine in the same proportion as in the previous example, but reckoning the power to remain the same throughout, the accompanying table (see pages 56 and 57) shows the quantity that will pass with the various splits.

Having explained in the remarks on the previous table how the quantities have been found, it seems unnecessary to do so in this case; indeed, the tables are so constructed as to obviate as much as possible the necessity of explanation. The results given in this table may be found more directly by using the relative powers in the third column of the table; the quantities will be according to the cube root of these:

$$\text{With 2 splits} = \frac{\sqrt[3]{\frac{.001}{.03225}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 19817.$$

$$\text{With 3 splits} = \frac{\sqrt[3]{\frac{.001}{.010259}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 29030.$$

$$\text{With 4 splits} = \frac{\sqrt[3]{\dfrac{.001}{.00490625}} \times 10000}{\sqrt[3]{\dfrac{.001}{.251}}} = 37123.$$

$$\text{With 5 splits} = \frac{\sqrt[3]{\dfrac{.001}{.003}} \times 10000}{\sqrt[3]{\dfrac{.001}{\cdot 251}}} = 43737.$$

$$\text{With 6 splits} = \frac{\sqrt[3]{\dfrac{.001}{.0021574}} \times 10000}{\sqrt[3]{\dfrac{.001}{.251}}} = 48818.$$

$$\text{With 10 splits} = \frac{\sqrt[3]{\dfrac{.001}{.00125}} \times 10000}{\sqrt[3]{\dfrac{.001}{.251}}} = 58558.$$

41. Mr. Atkinson, in his *Treatise on Ventilation*, gives the quantities that will pass "supposing a mine to have such shafts and airways that when there are five equal splits of air the shaft resistances amount to one-half of the resistances offered by the mine . . . if before splitting the air at all we had a

Divisions of the current.	Relatively.		
	s.	a.	$s\left(\frac{1}{a}\right)^s = u$
	1.	2.	3.
1 { Shafts.......	1	10	.001
Mine	2	2	.25
			.251
2 { Shafts	1	10	.001
Mine........	2	4	.03125
			.03225
3 { Shafts	1	10	.001
Mine........	2	6	.009259
			.010259
4 { Shafts	1	10	.001
Mine........	2	8	.00390625
			.00490625
5 { Shafts	1	10	.001
Mine........	2	10	.002
			.003
6 { Shafts	1	10	.001
Mine........	2	12	.0011574
			.0021574
10 { Shafts	1	10	.001
Mine........	2	20	.00025
			.00125

Actual.			
u.	s.	a.	$q = \sqrt[3]{\frac{u}{k s}} \times a$
4.	5.	6.	7.
260.4	12,000	100	10,000
65100.	24,000	20	10,000
65360.4			
2026.7	12,000	100	19,817$\frac{2}{3}$
63333.7	24,000	40	19,817$\frac{2}{3}$
65360.4			
6370 4	12,000	100	29,030
58990.	24,000	60	29,030
65360.4			
13322.5	12,000	100	37,123
52037.9	24,000	80	37,123
65360.4			
21786.8	12,000	100	43,737
43573.6	24,000	100	43,737
65360.4			
30295 9	12,000	100	48,818
35064.5	24,000	120	48,818
65360.4			
52288.3	12,000	100	58,558
13072.1	24,000	200	58,558
65360.4			

ventilation of 10,000 cubic feet of air per minute," with the same ventilating pressure in force (see page 57, fourth edition). As the figures are different from those obtained above, we have brought them into a tabular form, and worked out the pressure (p) from the formula $\frac{k\,s\,v^2}{a}$ (see page 60).

It may be submitted that had Mr. Atkinson's quantities been correct, the pressure (p) should have been the same all the way down in the table; but it will be seen that the results are slightly different.

42. Again we have brought Mr. Atkinson's figures of page 58, fourth edition, into a tabular form and applied the rules $u = q\,p = vap$ to ascertain the power, and find the results are not quite the same in each case, though the difference is not very much, as will be seen from the last column of the table on page 61.

42[a]. A number of uneven splits subject to common pressure may be converted to one typical road that will offer the same

resistance in passing the same quantity of air, in the following manner:

Let r=the sum of the separate results for each split of—

$$\frac{1}{\sqrt{\dfrac{\left(\dfrac{1}{a}\right)^2 \times s}{a}}}$$

Let a'= the area of the new typical road,
" s'=rubbing surface of ditto, then

$$\frac{\left(\dfrac{1}{r}\right)^2 \times a'}{\left(\dfrac{1}{a'}\right)^2}=s'$$

Example:—Reduce the three uneven splits below to one road 6 ft. square that will offer the same resistance with the same quantity, or pass an equal quantity with the same pressure.

	a.	s.	$\frac{1}{\sqrt{\dfrac{\left(\dfrac{1}{a}\right)^2 \times s}{a}}}$
1	30	59400	.674201
2	36	57600	.900009
3	35	72000	.771678
			2.345888

Divisions of the current.	s.	a.	q, as per Mr. Atkinson.	$p=\frac{ksv^2}{a}$
1 { Shafts..	12,000	100	10,000	.02604
Mine...	24,000	20	10,000	6.51
				6.53604
2 { Shafts..	12,000	100	27,892	.20258
Mine...	24,000	40	27,892	6.33067
				6.53325
3 { Shafts..	12,000	100	49,449	.63673
Mine...	24,000	60	49,449	5.89566
				6.53239
4 { Shafts..	12,000	100	71,527	1.33223
Mine...	24,000	80	71,527	5.20407
				6.53630
5 { Shafts..	12,000	100	90,789	2.14638
Mine...	24,000	100	90,789	4.29277
				6.43915
6 { Shafts..	12,000	100	107,800	3.02607
Mine...	24,000	120	107,800	3.50236
				6.52843
10 { Shafts..	12,000	100	141,710	5.22928
Mine...	24,000	200	141,710	1.30732
				6.53660

Divisions of the air current.		$s.$	$a.$	$q.$ as per Mr. Atkinson.	$p=\frac{ksv^2}{a}$	$u=qp=vap$
1	Shafts..	12,000	100	10,000	.026	260.4
	Mine ..	24,000	20	10,000	6.51	65100.
						65360.4
2	Shafts..	12,000	100	19,813	.1022	2025.31
	Mine ..	24,000	40	19,813	3.1940	63291.
						65316.31
2	Shafts..	12,000	100	29,022	.2193	6365.
	Mine ..	24,000	60	29,022	2.0308	58938.
						65303.
4	Shafts..	12,000	100	37,121	.3588	13319.
	Mine ..	24,000	80	37,121	1.4016	52028.
						65347.
5	Shafts..	12,000	100	43,736	.4981	21785.
	Mine ..	24,000	100	43,736	.9962	43570.
						65355.
6	Shafts..	12,000	100	48,797	.6200	30254.
	Mine ..	24,000	120	48,797	.7176	35017.
						65271.
10	Shafts..	12,000	100	58,556	.89286	52282.
	Mine ..	24,000	200	58,556	.22321	13070.
						53526.

$$\text{Then } \frac{\left(\frac{1}{2.34588}\right)^2 \times 36'}{\left(\frac{1}{3}\right)^2} = 8478\ s.$$

or $\frac{8478}{24} = 344\frac{1}{12}$; thus, a road 6 ft. square of this length or having a rubbing surface of 8478, will be equal to the three divided roads above.

Another example may be given to illustrate this rule. There are five unequal splits subject to one common pressure, with dimensions as below; find the value of s for a road 6 ft. square to give a resistance equal to that of all the splits together:

No.	Size.	Length.	$\dfrac{1}{\sqrt{\dfrac{\left(\frac{1}{a}\right)^2 \times s}{a}}}$
	ft. ft.		
1	8 × 3	1500	.6472313
2	5 × 5	1300	.7752171
3	4 × 5	1200	.6085806
4	6 × 6	1000	1.3942729
5	5 × 5	1300	.7752171
			4.2005190

Then $\dfrac{\left(\dfrac{1}{4.200519}\right)^2 \times 36'}{\left(\dfrac{1}{36}\right)^2} = 2644.24\ s$

the answer.

TO FIND THE QUANTITY THAT WILL RESULT FROM THE APPLICATION OF A GIVEN PRESSURE OR POWER IN A MINE HAVING UNEQUAL SPLITS, &C.

43. If there are a number of equal or unequal splits in a mine, all subject to one common pressure, the quantities that will pass in each split are in proportion to this formula:

$$\frac{1}{\sqrt{\dfrac{\left(\frac{1}{a}\right)^2 \times s,}{a}}}$$

or finding p for an equal quantity passing in each split, the quantities in each split will be in proportion to $\frac{1}{\sqrt{p}}$.

44. The relative pressures or powers to pass the same quantity of air through air courses of different areas and

rubbing surfaces may be found by $\dfrac{s\left(\dfrac{1}{a}\right)^2}{a}$ or $s\left(\dfrac{1}{a}\right)^3$ which formulæ we have used in obtaining the figures contained in the third column of each of the tables on pages 48, 49, and 56, 57.

45. When the air courses are of the same area and perimeter, and the pressure is the same, the quantities are in proportion to the reciprocal of the square root of the length $= \dfrac{1}{\sqrt{l}}$.

46. The water-gauge due to friction is 9 in. The downcast is 10 ft. in diameter and 70 fathoms deep, the upcast is 9 ft. diameter and 70 fathoms deep. The air courses underground are as follows:

One	900	yards long	6 ft. × 5 ft.
"	800	"	6 ft. × 6 ft.
"	1,000	"	7 ft. × 5 ft.

Find the quantity of air passing, applying Mr. Atkinson's co-efficient of friction throughout—

.9 in. × 5.2 = 4.68 lbs. pressure.

In this case we proceed to find the pressure necessary for passing 40,000, which altogether amounts to 8.8561 lbs., then as $\sqrt{8.8561}$: 40,000 : : $\sqrt{4.68}$= 29,077, as worked out in the table (page 67), the formula at the head of each column explains where necessary the manner of proceeding; it has been assumed that the splits are subject to one common pressure.

47. The next table (page 68) is given by way of exercise for the student—the question being, What quantity of air will pass through the mine with a total pressure of 8 lbs. per square foot, the current being divided as specified, Nos. 1 and 2 being the shafts, 3, 4, 5, and 6 splits, subject to the same pressure? It is not necessary here to explain how the figures in the first seven columns of this table have been obtained, but those of column 8 are on the assumption that 40,000 ft. of air pass through each division (any other quantity might have been assumed); column 9 is the reciprocal of the square root of the pressure given

Divisions of the air currents.	a.	s.	Relative pressures $= \frac{\left(\frac{1}{a}\right)^2 \times s.}{a}$	Square root of relative pressures $= \frac{\sqrt{\left(\frac{1}{a}\right)^2 \times S'}}{a}$ or $\sqrt{S\left(\frac{1}{a}\right)^3}$	Reciprocal of the sq. root of relative pressures=relative quantities= $\frac{1}{\frac{\sqrt{\left(\frac{1}{a}\right)^2 \times s.}}{a}}$	Quantities in direct proportion to relative quantities.	p, for assumed quantity $= \frac{k\,s\,v^3}{a}$	p=in direct proport'n to figures in previous col.	$q = \sqrt[3]{\frac{p\,a}{k\,s}}\,a$
Downcast.	78.54	13194.72				40,000	.9456	.4997	29,077
Upcast....	63.6174	11875.284				40,000	1.6014	.8462	29,077
1st air c'rse	30	59,400	2.1999956	1.4832382	.674201	11,496			8,357
2d air c'rse	36	57.600	1.2345332	1.1110999	.900009	15,346	6.3091	.3341	11,156
3d air c'rse	35	72,000	1.679296	1 2958768	.771678	13,158			9,564
					2.345888	40,000	8.8561	4.68	29,077

No.	Size.	Length.	Perimeter.	s.	a.	q.	$p = \frac{ksv^2}{a}$	$\frac{1}{\sqrt{p}}$	q.	p.	p in proportion to col. 11, total being 8 lbs.	Actual quantity for the total pressure of 8 lbs.	u.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1	8×8	900	32	28,800	64	40,000			40,000	3.814	2 147	30,012	64,436
2	7×7	900	28	25,200	49	40,000			40,000	7.437	4.187	30,012	125,660
3	8×3	1,500	22	33,000	24	40,000	82.88188	.1098424	7,558			5,671	9,448
4	5×5	1,300	20	26,000	25	40,000	57.77408	.1315629	9,053	2.959	1.666	6,792	11,315
5	4×5	1,200	18	21,600	20	40,000	93.74400	.1032828	7,107			5,332	8,883
6	6×6	1,000	24	24,000	36	40,000	17.86005	.2366237	16,282			12 217	20,354
								.5813118	40,000	14.210	8.000	30,012	240,096

in column 8. In column 10 we give the quantities that pass in each division when the total is 40,000; of course the two shafts (1 and 2) pass the total quantity of 40,000, and the quantity in each division underground is in direct proportion to the figures given in column 9. In column 11 it is seen that the total pressure required to pass 40,000 is 14.21 lbs., but as only 8 lbs. is the pressure in force, we proportion the figures in column 12 with those of 11, so that they amount to 8 lbs. and then we find if $\sqrt{14.21}$ give 40,000, that $\sqrt{8}$ will give 30,012, and that the quantities passing in each split 3, 4, 5, and 6 will be according to the figures given in column 13, and the total power (u) as per column 14, will be 240,096.

48. By way of exercise for the student it has been further assumed that another air course (No. 7) 5×5 and 1,300 ft. long be added to those enumerated in the previous paragraph, and that the power in force remains the same. With these conditions the quantity passing, it will

be seen, is only increased from 30,012 to 30,744, as per table on page 71.

In this case we have proportioned the quantities in each split by the figures in column 7; and in taking 30,012 as the total quanity of air passing, we find the pressure, as per column 9, to be 7,442; this multiplied by the quantity gives 223,349 units; then we find if $\sqrt[3]{223349}$ give 30,012 that the $\sqrt[3]{240096}$ gives 30,744, and the quantity in each split is proportioned again according to the figures in column 7. The pressure, p, in column 11 may be obtained by proportioning it with the figures in columns 8, 9, and 10, or by working out directly from the quantity in column 10 by the formula—$p = \frac{k\,s\,v^2}{a}$, and u in column 12 is obtained by multiplying the figures in columns 10 and 11 together; and it will be seen that the total units in this column amount to 240,098, which is correct within 2 units in the previous table.

49. Suppose a mine to have two splits of air only, one offering five times as

No.	Size.	Length.	Perimeter.	s.	a.	$\dfrac{1}{\dfrac{\sqrt{\left(\frac{1}{a}\right)^2 \times s}}{a}}$	q.	p.	q.	p.	u.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	8×8	900	32	28,800	64		30,012	2.147	30.744	2.2533	69,275
2	7×7	900	28	25,200	49		30,012	4.187	30,744	4.3933	135,068
3	8×3	1,500	22	33,000	24	6473508	4,624		4,737		5,509
4	5×5	1,300	20	26.000	25	.7054475	5,539		5,674		6,599
5	4×5	1.200	18	21,600	20	.6085806	4,348	1.108	4,454	1.163	5,180
6	6×6	1,000	24	24,000	36	1.3942729	9,962		10.205		11,868
7	5×5	1,300	20	:6,000	25	7054475	5,539		5,674		6,599
						4.0610993	30,012	7.442	30,744	7.8096	240,098

much resistance as the other, and that the ventilating pressure required to circulate the air through the shafts and undivided airways is one-twelfth of the whole ventilating pressure. With a total quantity of 100,000 feet passing per minute, and putting the rubbing surface of the shafts at 10,000 and area at 100, then the figures in the table below will show the relative rubbing surfaces, areas, quantities, and pressures meeting these conditions.

Divisions of the air.	*s.*	*a.*	*q.*	*p.*
Shafts........	10,000	100	100,000	2.17
Mine.	1,151,912	100	30,902	23.87
	230,388	100	69,098	
				26.04

50. If the pressure remain the same as stated in previous paragraph, and there are three splits offering resistances in the ratio of 3, 2, 1, then the relative quantities, rubbing surfaces, areas, and pressures will be according to the following table:

Divisions of the air.	*s*.	*a*.	*q*.	*p*.
Shafts........	10,000	100	148,869	4.81
Mine	691,150	100	37,623	21.23
	460,767	100	46,079	
	230,383	100	65,167	
				26.04

The examples given in this and the previous paragraph are to be found in another form at page 182 in the Transactions of the North of England Institute of Mining Engineers, Vol. VI.

51. If the downcast and upcast shafts of a colliery are each 180 fathoms deep and 12 ft. 5 in. diameter, and with one undivided air course in the mine having $a=36$ and $s=120,000$, the quantity of air circulating is 15,000 cubic feet per minute, what quantity will pass when there are 2, 3, 4, 5, and 6 equal splits, the pressure remaining the same? In the first place we find the total pressure required to pass 15,000 ft. of air with only one air course is 12.78954 lbs., then we find what the relative pressures are

No	Divisions of the current. 1.	a. 2.	s. 3.	Relative pressures on a quantity of 15,000 = $\frac{k s v^2}{a}$ 4.
1	Shafts...	121.087	84,240	
	Mine ...	36	120,000	
2	Shafts...	121.087	84,240	.231669
	Mine ...	72	120,000	1.569734
				1.801403
3	Shafts...	121.087	84,240	.231669
	Mine ...	108	120,000	.465106
				.696775
4	Shafts...	121.087	84,240	.231669
	Mine ...	144	120,000	.196217
				.427886
5	Shafts...	121.087	84,240	.231669
	Mine ...	180	120,000	.100463
				.332132
6	Shafts...	121.087	84,240	.231669
	Mine ...	216	120,000	.058138
				.289807

p.	*q*.	*u*.
5.	6.	7.
.231669	15,000	3,475
12.557871	15,000	188,368
12.789540		191,843
1.644796	39,968	
11.144744	39,968	
12.789540		511,172
4.252363	64,265	
8.537177	64,265	
12.789540		821,920
6.924602	82,008	
5.864938	82,008	
12.789540		1,048,845
8.920971	93,082	
3.868569	93,082	
12.789540		1,190,476
10.223839	99,647	
2.565701	99,647	
12.789540		1,274,439

on 15,000 in the case of all the splits, as per column 4; the pressure in column 5 is then apportioned directly according to the figures in column 4; and from the pressure in column 5 we get the quantity in column 6 by the rule—$\sqrt{\frac{p\,a}{k\,s}} \times a$ and u is got by multiplying p and q together.

Supposing it be required to know what quantity will pass with the power (u) remaining the same, we find by the table that this amounts to 191,843 units when the air is passing round the mine in one current, then by the table we see that with the same pressure there are 39,968 feet of air passing with two splits, and that the power (u) amounts to 511,-172, then we say

As $\sqrt[3]{511172} : 39968 :: \sqrt[3]{191843} : 28666$, the quantity of air that will pass when there are two equal splits, and the power remains the same, or we work out the results in the case of all the splits as follows:

$$\text{With 2 splits} = \frac{\sqrt[3]{191843} \times 39968}{\sqrt[3]{511172}} = 28666$$

$$\text{With 3 splits} = \frac{\sqrt[3]{191843} \times 64265}{\sqrt[3]{821920}} = 39347$$

$$\text{With 4 splits} = \frac{\sqrt[3]{191843} \times 82008}{\sqrt[3]{1048845}} = 46291$$

$$\text{With 5 splits} = \frac{\sqrt[3]{191843} \times 93082}{\sqrt[3]{1190476}} = 50370$$

$$\text{With 6 splits} = \frac{\sqrt[3]{191843} \times 99647}{\sqrt[3]{1274439}} = 52617$$

ASCENSIONAL VENTILATION.

52. By ascensional ventilation is meant the art of conducting the air underground so that it shall in the first place go directly to the lowest part of the workings and afterwards rise as it returns to the bottom of the upcast shaft. The intake generally being colder than the return, by this system return air is made to ascend and not descend. There is a loss of power in conducting return air downwards to the upcast, and this is a practice that should be avoided as much as possible.

53. The rules and tables referring to the friction of air and to the different quantities that will circulate with certain pressures, as given in the previous chapters, apply only to horizontal channels and not to dip and rise roads; for in practice it is found, whilst the quantities of air that will pass in different splits

in the same horizontal plane preserve the same proportion whatever the ventilating pressure may be, such is not the case with dip and rise plits.

54. The reason of this is that there is a difference between the density of the intake and return air due to change of temperature, the mixture of watery vapor, the emission of gases, &c., and as the return air of any current is generally less dense than the intake (on account of the gases emitted being usually lighter than common air, &c.) there is mostly a natural influence at work in favor of the intake current passing to the dip, and returning by an ascending route, and against the air going first to the rise and returning by a descending road. Supposing a dip and rise split to be subject to one common ventilating pressure, in the case of the dip split there is to be added the pressure due to natural influences, in the case of the rise split the pressure due to natural influences is to be deducted from the general ventilating pressure, and thus it happens if there be

a long split and a short one, both level, in order to pass equal quantities of air in each it will be necessary to put a regulator in the short one; and on reducing or increasing the ventilating pressure the quantities will still be equal, but if the long one is a dip split and the short one a level one, on reducing the total quantity of air the long split will get a greater proportion than originally. On the other hand, if the long split is a rise one and the short split a horizontal one, on reducing the total quantity of air the long split passes less and the short one more than the original share. This fact, so repeatedly proved in practice, clearly shows the value of the principle of ascensional ventilation and the mistake in carrying return air down the bank. If, however, the returns were charged with gases heavier than common air to such an extent as to render them more dense than the intake air, the opposite results would take place on reducing or increasing the general ventilating pressure n the case of dip and rise splits. This,

however, is an exceptional case, for, as said before, the return air of mines is generally less dense, in consequence of being usually higher in temperature, and impregnated with the lighter gases; and it is therefore, speaking generally, wrong in principle to bring return air down the hill. The descent of return air in places which give off fire damp has been, and is likely to be, the cause of serious explosions.

55. In collieries giving off fire damp it is well to have the return air course on the upper side of the workings; by this means the gas will be naturally drained away by gravity from the goaves or where workmen are employed.

56. If the ascensional principle of ventilation be carried out, the exudation of carburetted hydrogen in a mine will have the effect of increasing the ventilation. The light specific gravity of the fire damp, as compared with that of air, will be equal to an additional ventilating pressure. This principle appears to be well understood in Belgium and in West-

phalia, particularly so in the last-mentioned coal field, where, according to the experience of the writer, it is the prevailing system.

57. In furnace ventilation the best current of air is produced by having the furnace placed on the dip side of the underground workings, because in that case a longer motive column or ventilating pressure is obtained; but in steep-lying seams the advantage derived by the natural ascendency of warm air and light gas is not only lost, but an additional pressure equivalent to this advantage is required to bring the light air down to the bottom of the upcast. Hence, ventilating fans made to exhaust the air from a shaft on the rise side of the workings are both in point of economy and safety better for ventilating steep seams than furnaces placed on the dip side.

58. If we suppose the rise workings to reach the vertical height of 50 fathoms, and the temperature of the intake be 55 degs. and return 85 degs., there will be a natural pressure due to tem-

perature alone of 1 lb. per square foot, or one-fifth of an inch of water gauge in favor of mechanical ventilation with upcast shaft at the rise of the workings, and against furnace ventilation with the upcast at the dip, in addition to the extra resistance consequent on the increased length of air course and upcast. In order to make this plain to the student, we take from the table of the weight of air given under paragraph 6 the weight of a foot at 55 degs.=.0773515, and multiply this by 300=23.20545, and deduct the weight at 85 degs.=.0730858 multiplied by 300=21.192574, which gives a difference of 1.01 lb.

59. The average temperature of a furnace upcast may generally be taken at 100 degs. (at least) more than that of the mine, and consequently the increased pressure obtained at the bottom of the upcast by this increased length of heated air column will overcome any local pressure in the mine and compel the air to travel down-hill from the rise workings

to the furnace, but this will be at the expense of additional fuel.

60. It has been stated that the gases emitted from mines are generally such as to render the return air lighter than the intake. This, however, depends on the specific gravity of the gas. The table following shows the specific gravity of the various gases met with in mines and the relative altitude they usually assume:

	S. G.
Hydrogen	0.069.
Carburetted hydrogen	0.550.
Aqueous vapor	0.620.
Nitrogen and miasma	0.976.
Olefiant	0.980.
Air	1.000.
Oxygen	1.100.
Sulphuretted hydrogen	1.190.
Carbonic acid	1.520.
Sulphurous acid	2.120.

Those gases which are lighter than air have an influence in favor of the ascensional principle of ventilation; those which are heavier will act prejudicially to it.

VELOCITY OF AIR.

61. A velocity of 6 in. per second or 30 ft. per minute is enough to deflect the flame of a candle, and 3 ft. per second is sufficient to remove and render harmless the ordinary discharges of fire damp. A return air course 7 ft. square passing 30,000 cubic feet of air per minute gives a velocity of about 10 ft. per second. In many of the furnace pits of the North of England the air travels at a velocity as high as 30 ft. per second. It is not always practicable, however desirable, to reduce the velocity in returns or upcast shafts to a minimum, but it is very important that the air in the working parts of a mine should not travel at less than say 2 ft. per second, or more than 7 ft. The medium between these would be the best average velocity; but a very much greater velocity than this is attained in some collieries.

62. There are several reasons why air should not travel at a high velocity. One is because, if it be very much surcharged with fire damp, enough to render it inflammable, there is a danger of some of the commonly used lamps exploding. Another reason is that the pressure required to overcome the friction is according to the square of the velocity, and the power according to its cube. The following table shows the relative pressures and powers required to move the air through the same air course at the velocities stated:

Velocity in ft. per second.	Relative pressures.	Relative powers.
3	1.	1.
4	1.77	2.37
5	2.77	4.63
6	4.	8.
7	5.44	12.70
8	7.11	18.96
9	9.	27.
10	11.11	37.03
12	16.	64.
14	21.77	101.63
16	28.44	151.70

Thus we see there is 16 times the pressure and 64 times the power required to pass the air through the same channel, at a velocity of 12 ft. per second, that is necessary at 3 ft. per second. Thirdly, when air travels too rapidly it is disagreeable to the workmen and all who have to move in it; and it is difficult to prevent the light from being blown out.

63. Each split should have a current of 8,000 or 10,000 cubic feet per minute, and the latter quantity at a velocity of 5 ft. per second would require an area of 33 square feet.

An inflammable mixture of pit gas and air, moving at the rate of 8 ft. per second, will explode most of the ordinary safety (?) lamps.

THE CO-EFFICIENT OF FRICTION.

64. Throughout this treatise we have used the co-efficient of Mr. Atkinson, namely, .0000000217 lb. for each foot of rubbing surface, and a velocity of 1 ft. per minute. From this we find that $v=6788$

$\sqrt{\frac{pa}{s}}$, because $\sqrt{\frac{1}{.0000000217}}=6788.$

65. Mr. D. K. Clark, in his most excellent book, *Rules, Tables and Data for Mechanical Engineers*, gives the following formula for the "flow of air through passages of any form of section" (substituting the notation used throughout these papers it is):

$$v=796\sqrt{\frac{wa}{s}}$$

and to bring this into the same terms as above:

$$\frac{796 \times 60}{\sqrt{5.2}} = 20{,}944,$$

therefore :

$$v = 20{,}944\sqrt{\frac{pa}{s}}$$

66. M. Devillez, in his *Ventilation des Mines*, uses a co-efficient which is equal to .00000000951 lb. for each foot of rubbing surface and a velocity of 1 ft. per minute, now as :

$$\sqrt{\frac{1}{.00000000951}} = 10{,}253 \quad v = 10{,}253\sqrt{\frac{pa}{s}}$$

67. Recapitulating, we see that the velocity is found according to these three authorities as below :

Per Atkinson, $v = 6{,}788\sqrt{\frac{pa}{s}}$

Per Devillez, $v = 10{,}253\sqrt{\frac{}{s}}$

Per Clark, $v = 20{,}944\sqrt{\frac{pa}{s}}$

68. The writer is inclined to think that Mr. Clark's formula is deduced from experiments with passages having

smoother sides than those of underground roads generally, and consequently the friction is not so great; he has confidence in the result obtained by M. Devillez, but thinks until further experiments have been made it would be sufficiently near, as an average for underground passages, to use $10,000\sqrt{\frac{pa}{s}}$.

This would be equal to .00000001 pound per square foot of rubbing surface, or $\frac{1}{100,000,000}$ for a velocity of one foot per minute, or .01 lb. or $\frac{1}{100}$ for a velocity of 1,000 ft. per minute, and these are factors that could be both easily remembered and used in calculation.

NOTE.

69. In the preceding pages calculations have been gone into to show the quantities of air that will circulate under certain conditions; it is necessary to state that these conditions never exist practically; for example, "equal splitting," as has been explained under paragraph 31, cannot very well exist in a practical sense; then again, in considering "unequal splitting," it has been assumed that the splits are all subject to one pressure; this can only be the case when all the splits divide from the main current at one point, and reunite again in the return at one point, which will not be found to be the case practically. It has already been pointed out in the earlier pages that one of the conditions—assumed to exist — is wanting in the case of dip and rise splits. Another condition affecting the consideration of

the quantities that will pass with various powers or pressures is the co-efficient of friction; in the calculations it has been assumed that one co-efficient applies throughout the whole ramifications of the mine, from the entrance of the air at the mouth of the downcast till it escapes at the top of the upcast; but from experiment it has been found that the co-efficient varies with the nature of the rubbing surface; that in an arched tunnel or brick-lined shaft for example, it is not nearly so much as for the ordinary channels of a mine. It has likewise been assumed that all the air which enters the mine passes completely through it, but this is not the case practically; air escapes at doors, stoppings, crossings, brattice, and through goaves, &c., and this to a very large extent in some collieries.

70. The amount of this fugitive air, if it may be so called, is not always a criterion of the ability displayed in carrying out the ventilation; in collieries having good means of producing air, and with

limited workings, it is more permissible than in extensive collieries which require all the air in-bye that can be obtained; in such cases as the latter care must be taken to prevent the escape of air by taking the short route to the return, instead of passing through the working places.

71. All open places in a coal mine, whether in work or not, should have air passed through them, and in no case should old workings be shut up with air-tight stoppings; such a practice is very likely to lead to some casualty through places of this kind becoming dangerous magazines of gas.

72. It is hoped the calculations that have been gone into may be of some assistance to students in understanding the question. The principal matter of this essay was worked out some twelve months ago, when the writer intended to consider the subject further; since then, however, his engagements have prevented him from devoting the necessary time to it, and for this reason certain experiments on the subject cannot at present be utilized.

THE VENTILATION OF COAL MINES.

BY

GEORGE J. ANDRÉ.

The late coal panic has shown us to what degree our material prosperity is dependent on that mineral. It would seem, indeed, that the exhaustion of our coal fields must inevitably be followed by the utter collapse of those industries which have made this country what it is, and that even a slightly decreased production would seriously affect their position. Coal having assumed a relation of such vital importance to our social existence, its extraction from the earth has become one of the foremost engineering questions of the day, and accordingly increased attention is now being directed to it. The author of the present paper has therefore deemed the time opportune for a discussion of some of the facts relating to what is certainly one of the most important subjects of mine engi-

neering, namely, the ventilation of the workings. One of the effects of the recent panic may be seen in the greater activity shown at existing collieries as well as in the opening out of many new ones. In their haste to extract the valuable mineral there is danger that managers and engineers may not give due attention to those matters which are essential to an efficient ventilation, especially in the laying out of new works. Hence another reason for calling attention to the subject at this time. Moreover it is almost an indisputable fact that 90 per cent. of those disastrous explosions which so frequently occur are wholly due to a defective ventilation. Thus it appears that, though the principles of a good ventilation are generally understood and acknowledged in theory, they are still far from being applied in practice. By the expression "defective ventilation," it is not intended to mean merely insufficient ventilation, but also all systems of ventilating a mine that are established upon false principles, quite

irrespective of the quantity of air passing through it in a given time. Of course it is quite impossible to treat so large a subject in a paper like the present, and therefore no such attempt will be made. All that the author proposes to do is to direct attention to a few essential points, and instead of adducing anything new, to simplify what is already known.

It is agreed on all hands, and Parliament has recently enacted, that a sufficient quantity of air should be constantly passed through a mine to dilute and render harmless the noxious gases evolved or generated therein. But there does not appear to be any definite understanding among mining men as to what constitutes a sufficient quantity, and the practice among careful men is to pass an excess of air in order to be on the safe side. No doubt this is erring in the right direction; but it is better not to err at all. Besides, such a practice begets a vagueness of notion concerning the requisite quantity of air that con-

duces neither to correctness of judgment nor to progress in knowledge. It may in some cases be a source of danger even, for a Davy lamp is not safe in a violent current of air that has been suddenly fouled by a blower, while the cost of producing the current is enormously increased. Of course the question is an intricate and a difficult one, depending upon numerous conditions that vary from district to district, and even from mine to mine. A general solution is therefore not to be looked for; but it is both practicable and highly desirable to lay down some definite and invariable basis upon which every individual case may be accurately and readily calculated.

The atmosphere of a coal mine is vitiated by several causes: the breath of men and horses, the combustion of lights, the moisture of the ground, the exhalation of gases from the strata, and the chemical changes which are constantly going on in the substances exposed to the influence of the air. Some of these causes are constant in their action or

nearly so, while others are extremely variable. The former we can estimate with accuracy; with the latter we can deal only approximately.

The average quantity of air breathed by man is usually assumed by writers on mine ventilation to be 800 cubic feet per minute. This quantity is, however, altogether erroneous as a basis on which to calculate an adequate amount of ventilation. It has been stated by eminent medical authorities that the mean of several hundred experiments conducted with great care by means of very accurate instruments was 502 cubic inches per minute, and that this quantity was increased to 1,500 cubic inches, or nearly three times as much, by the exertion of walking four miles an hour. We all know from experience that a much larger quantity of air is breathed when undergoing violent exercise than when at rest; and we cannot therefore found a calculation relating to men subjected to great physical exertion in a mine upon what has been ascertained respecting a

man lying motionless on his bed. It may be assumed that the average amount of labor undergone by each man and boy in the extraction of coal is at least equal to that of walking four miles an hour; and hence the quantity of air required for each man will be 1,500 cubic inches, or say, one cubic foot per minute. The miasmata or effluvia derived from the various secretions of the body are a potent cause of vitiation in the atmosphere. The unpleasant smell of a close bedroom in the morning is due wholly to this cause, and in ascertaining the state of ventilation in a room by what is known as the "nose test," it is these effluvia which furnish the requisite indications. Moreover, the air in passing over the human body becomes heated. These causes are greatly increased in intensity by the augmented temperature due to violent exertion, such as is undergone in mines. Added to this there is the dust caused by each workman floating in the atmosphere. We must therefore provide an additional quantity

of air to keep the atmosphere pure and cool, and this quantity may be taken as one cubic foot per minute. This allows a covering of film of air over his whole body about $\frac{3}{4}$ inch thick, which film is changed every minute. Each man's lamp will heat the air and foul it with the products of combustion to a degree requiring about one cubic foot per minute. Thus the quantity of air requisite per man will be three cubic feet per minute. A horse fouls about six times as much as a man, and will therefore require twelve cubic feet per minute.

The foregoing may be considered the constant causes of vitiated air, and are easily dealt with. We come now to consider the varying causes, namely, the moisture of the ground and the gases evolved. It is impossible to treat these otherwise than approximately, but an approximation sufficiently near for practical purposes may be arrived at. The gases existing in a coal mine are chiefly carbonic acid or choke-damp and carburetted hydrogen or fire-damp. Other

gases are generated, but in such small quantities that their presence is not of much importance, except perhaps when blasting is extensively practiced. These two gases, carbonic acid and carburetted hydrogen, are continually being exhaled in greater or less quantities from the face of the exposed strata, and therefore the total quantity is to a certain degree dependent on the extent of surface exposed. They are given off more abundantly from fissures, especially in the neighborhood of faults. Considerable quantities of carbonic acid are also in every mine due to the respiration of men and horses, the combustion of lights and the deflagration of gunpowder, all of which causes are subjects of calculation. In smaller quantities, carbonic acid is formed by the fermentation and decomposition of vegetable matter.

When the proportion of carbonic acid to the atmospheric air reaches $\frac{1}{10}$th the compound will not support combustion, and is fatal to life. A proportion of $\frac{1}{15}$th of carburetted hydrogen renders the

compound inflammable. These proportions may be taken as the limits which must never be reached; or, to further simplify the matter, the proportion of pure atmospheric air must, in a mine, never be less than $\frac{14}{15}$ths of the total volume therein contained.

The question now is what quantity of air in a dry mine, making but little gas of any kind, is sufficient, irrespective of the respiration of men and horses, to ensure this proportion under all conditions. This problem, as we have said, can only be solved approximately, but as it is mainly a matter of experience and calculation, a fairly close approximation may be arrived at. A careful investigation of this matter has led the author to conclude that one cubic foot of air per second for every 100 square yards of surface is an adequate quantity. This allows for the exhalation and formation of .067 cubic foot of impurities, that is, noxious gases, watery vapor, and solid floating matter per second. In other words, one cubic foot of air per 100

yards of surface is equivalent to a film about $\frac{3}{4}$ inch thick spread over that surface, which film is changed every minute. And .067 cubic foot of gases to the same extent of surface is equivalent to a film about $\frac{1}{20}$ inch thick formed every minute. Of course the gas is not exhaled in this regular way over the whole surface exposed. But the quantity here given is approximately that which is given off the surface at the worst parts under the conditions previously mentioned.

This quantity of one cubic foot per second for every 100 yards of surface may be taken as a reliable basis upon which to calculate an adequate ventilation. It must be borne in mind that the quantity is only just sufficient under the very favorable conditions which we have assumed, and is, therefore, analogous to the breaking strain of materials. In every case it will have to be multiplied by an appropriate factor of safety, the value of which must be determined by the conditions of the case. All mines

are, in a greater or less degree, liable to give off "blowers," that is pent-up accumulations of gas which are liberated by the boring and driving, or by falls of roof. The gas issues from the blowers with a sound resembling, in the smaller ones, the simmering of a tea-kettle, and in the larger that of blowing off high-pressure steam. Of course it is quite impossible to estimate the value of these blowers with anything like accuracy, just as it is impossible to estimate the value of the strain to which a structure exposed to sudden shocks may be subjected. In both cases a sufficiently large factor of safety must be taken to include possibilities and to leave an ample margin of safety. It may be remarked that no system of ventilation can be calculated for the large blowers previously mentioned. They are fortunately of rare occurrence, and when one does occur, the only practicable plan is to call out the men until it has exhausted itself. When their presence is suspected, safety lamps alone should be used. The small blowers

are more constant in their action, and are capable of being estimated with some degree of precision.

Besides varying in gaseous products, mines differ in degree of moisture. Blasting is also more extensively practiced in some mines than in others. All of these circumstances will influence the factor of safety, the value of which must be determined for every individual case, and which will vary from 2 to 6. Let us now apply these principles to an example. Suppose we have to ventilate a mine in which the air courses have a total length of 2,000 yards, giving a total surface of, say, 14,000 square yards; and, to simplify the calculation, we will suppose that the number of men and horses are 100 and 10 respectively. Respiration, perspiration, and lamps will then require $100 \times 3 + 10 \times 12 = 420$ cubic feet per minute; and the gases, vapors, &c., will need $\frac{14000}{100} = 140$ cubic feet per second= 8,400 cubic feet per minute. Supposing the mine to generate but little fire-damp and to be not particularly wet, we may

take the factor of safety at 3, which will give $(840^{\circ} + 420) \times 3 = 26{,}460$ cubic feet per minute as the adequate amount of ventilation. In this case we have taken the surface and the factor of safety for the entire mine; but when, as it usually is, the mine is divided into several districts, which are aired by separate currents, the air must be apportioned according to the surface of each district and the factor of safety determined by the nature of the seam or the conditions of the workings. Thus the factor of safety may vary from district to district.

When the proper quantity of air has been determined, the next question is, how to get it through the workings. One mode of effecting this is to provide contracted air-ways and to give the ventilating current a high velocity. Another is to have spacious air-ways and a low velocity. For economical reasons, the former is but too frequently adopted. In many cases a drift is driven with an insufficient sectional area; in other cases,

falls of roof, the creep of the floor, and other causes reduce the dimensions of an air passage to those of a mere creeping hole. Fully 25 per cent. of the air courses in collieries which are now being worked, and in which the ventilation is said to be perfect, can only be entered by a man in a crawling posture. The economy of a system that lays out works in such a manner, or that allows them to get into such a condition, is more than doubtful. The drag of the air, that is, its retardation by contraction and friction, is enormously increased thereby, and the consumption of fuel in the furnace, or in the engine when a mechanical ventilator is used, is augmented in a like proportion. But even when the additional cost of fuel is incurred, the friction with small passages and high velocities is so great that it is impossible to ensure sufficient ventilation at all times, and hence there is the constant risk of accident, with its accompanying danger to life and property. It may therefore be laid down as one of the es-

sential principles of an efficient ventilation, that spacious air-ways are indispensable. A limit that may be adopted with advantage is, that all air-ways other than shafts should allow a sufficient quantity of air to pass with a velocity not exceeding 6 feet per second.

Another important fact connected with the dimensions of air-ways is, that the return passages require a larger sectional area than the intake passages. When the ventilating current enters the return ways from passing through the workings, it is laden with the various gases that are generated in a mine, watery vapor, the solid products of combustion and coal dust, and its temperature, and consequently its bulk, is considerably increased. Thus it has lost a great part of its elasticity and it drags more heavily. To compensate this, its friction should be lessened by increasing the sectional area of the passage. To ensure a proper state of ventilation there should be two return ways, each equal in sectional area to the intake. As far as practicable, the

air courses should have at all parts of their length the same sectional area. It is, perhaps, hardly necessary to remark that they should be kept free from all obstructions, such as projecting pieces of timber or stones.

One of the most effective means of diminishing the friction is to shorten the runs by dividing the workings into districts and ventilating each with a separate air-current. Thus, a shaft 12 feet in diameter will afford sufficient area for five different air-ways each of 20 feet area. This system of splitting the air, as it is called, though well known, is not adopted so extensively as it ought to be. There are many mines in which the old unwholesome and dangerous practice of passing the air through in one column from the downcast to the upcast shaft still prevails, though the evils attending it have long been acknowledged by the majority of viewers. An additional and great advantage possessed by the system of ventilating by districts is that of confining the effects of an explosion to a

small part of the workings. In all cases of splitting the air, the split should be made as near the downcast shaft, and the several branches reunited as near the upcast as possible, and the air-ways between the shafts and the points where the branches separate and reunite should have a large sectional area.

The distribution of the air through the workings requires great skill. There are, indeed, few matters connected with mining that test the skill and ability of the engineer more than this. A very slight variation in the direction of the ventilating current may make all the difference between a good and a defective, and consequently a dangerous ventilation. And yet this important duty is often left to ignorant hands. No doubt the men who are entrusted with this important work are experienced men, and men who on that account would be called practical. But there are things which experience alone cannot teach, at least in the lifetime of a single individual. A certain amount of scientific knowledge

and an acquaintance with collateral subjects, such as the composition of gases, the nature of fluids, and the laws which they obey, are absolutely necessary to enable a man to manage efficiently the ventilation of a mine. And such knowledge is part of a liberal education.

The essential conditions of a good distribution are: (1) That the air shall not pass from the broken to the whole workings; and (2) that an explosion shall not take the air off the men at the faces of work, or reverse its direction.

The author does not hesitate to assert that three-fourths of the explosions that occur, and that result in such a lamentable destruction of life and property, are caused solely by the neglect of the former of these conditions, and are therefore preventable; and that a large proportion of the deaths that result are due to the neglect of the latter conditions; for in most cases fewer men are killed by the direct effects of the explosion than by the after-damp. It does, indeed, seem strange that such an ignorant mode of

distributing the air should still be commonly adopted. When the ventilation is in uneducated hands we may attribute the practice of the pernicious system to ignorance and want of skill; but when, as is sometimes the case, we find the practice perpetuated under the authority of men eminent in their profession, we are forced to believe that a criminal economy is at the bottom of the matter.

The second condition is scarcely of less importance than the first, as it deals with the effects of an explosion should such an accident occur from any unforeseen cause. The ventilating current will always take the shortest course to the upcast shaft. If, in consequence of an explosion, the doors or stoppings are injured, a large portion of the workings may be left entirely without air at a time when it is most needed, namely, when the passages are foul with the after-damp or carbonic acid gas produced by the explosion. To prevent such an occurrence the distribution should be so arranged as to preclude the possibility

of the current of air being diverted from its proper course before it has left the working places, or of being stopped altogether by an injury to the return passage. All permanent stoppings should be built of brick or stone and well plastered; they should also be well backed, especially those by the side of the main ways, which should have five or six yards of stowing behind them. Whenever a crossing is necessary for the return it should, if possible, be by a stone drift over or under the main way. The additional cost thus incurred would be more than compensated by the additional security obtained. Were all these precautions duly observed, mining would be freed of half its perils. A strict supervision would be all that was necessary to protect the mine against the danger of an explosion occasioned by any but unforeseen causes. Such supervision is indispensable in all cases to ensure the proper quantities of air being apportioned to the several districts, and the needful precautions constantly taken

to maintain a steady, uniform current of air. Without this the best system must prove ineffectual.

DISCUSSION.

Mr. Baldwin Latham said he would offer a few remarks in order to open the discussion, but his observations would be on the general question of ventilation rather than with particular reference to coal mines. He had certainly given some attention to the ventilation of coal mines when studying the ventilation of sewers; but he had found that the system of having one downcast and one upcast shaft for the ventilation of coal mines was comparatively easy to carry out, but that it was not at all applicable to sewers. From his examination of a large number of coal mines he was convinced that the observations which had been made by Mr. André in his paper were of very great value. The paper did not touch upon the particular means which were adopted for the ventilation of coal mines, but it simply brought for-

ward broad facts which it would be well for all interested in such matters to bear in mind, and which showed that there never could be safety without a superabundance of fresh air. There was not sufficient attention paid to the ventilation of a mine as the workings were worked out, or as the material was extracted. In his opinion a new mine required far less air than one which had long been at work.' The little passages which were shown in the diagrams were air-channels; and in a new mine the cubic capacity of those channels would be comparatively small; but when the mine was worked out the cubic capacity became greater. When gases escaped or blowers occurred the passages and goaves acted as gas-holders by means of which gas could be accumulated. In an old mine the same intake and the same volume of air passed through it as in a new mine, although the cubical capacity in the old mine was greater. The chances were that in old mines the whole area might become occupied with gas which, by the admix-

ture of the atmospheric air, in limited quantities, would be rendered explosive. Instead of being diminished as the mine was worked out, and the cubical capacity of the mine became greater, the amount of air ought to be increased, and not only so, but adequate mechanical arrangements ought to be introduced by which the air could be conducted through the vacant spaces so as to completely ventilate the mine.

It was a disputed point whether natural or mechanical means ought to be adopted for ventilating mines. By mechanical means, he meant the use of steam as a mechanical power, for either driving air into the mine or sucking air out. The plan of driving air into a mine was called the plenum system, and the plan of drawing air out was called the vacuum system. The natural system of ventilation consisted of those methods in which the air of a mine was heated by ordinary combustion, so that they got a column of heated atmospheric air which was considerably lighter than an equal

column of cooler air, and by this difference in the weight of respective columns of air, motion was produced. Air upon being heated dilated $\frac{1}{490}$th of its own bulk for every degree Fahrenheit. Hence he fully corroborated the statements of Mr. André, that the passage for the exhausted air required to be far larger than the passage for the intake air. Air always passed into a mine at a temperature far lower than that of the air some hundreds of yards below the surface of the earth. The air of a furnace was applied in order to heat air in excess of atmospheric heat, and create that current of air which is necessary to aerate every part of the mine. A cubic foot of air heated 50 or 60 or perhaps 80 degrees would occupy a far larger space than it originally occupied when it entered the mine. This caused the necessity for increasing the size of the air-passage for all air which had once passed through the mine. If this was not done there would be a contraction, and contraction meant waste of force, and it also meant

retardation of ventilation. Further, it was possible when there was a contracted passage that from some sudden cause, such as the explosion of gunpowder in the mine, the whole current of ventilation might be changed in the opposite direction. Therefore it was needful in all cases of mine ventilation to make the passage of the air as easy as possible, from the place where it entered to the place where it passed out. If the passages were uniform throughout, some circumstances might momentarily change the direction of the air, and the result to those who were laboring in the mine might be an immense loss of life. Hence the necessity of producing enlarged passages for the easy exit of the air that had been used in the mine. Air would always take the shortest passage. We might make passages for it, but it would not follow the route prescribed for it if it could get away by any shorter cut.

Mr. Arthur Rigg said that the mechanical system of ventilation most gen-

erally adopted consisted in the use of fans, and they might be employed in two ways, either for forcing air into the mine (the plenum system) or for drawing air out (the vacuum system). Of those two, even on theoretical grounds only, the vacuum system appeared the best, for in the plenum system whatever moisture happened to be contained in the atmosphere at the time the air was compressed would be liable to be deposited; but in the vacuum system, on the contrary, the air, being attenuated, was in a condition to take up a far greater amount of moisture on leaving a mine than it could hold on entering. No doubt Mr. André was perfectly correct with his remarks on the dimensions of the passages, for in order to force a certain quantity of air through them if the passages were half the area, the air would have to travel with double velocity, and hence require about four times the power to drive it. There was an enormous economy in having the passages large, and the saving of three-

quarters of the coal which would have to be burnt when narrow passages were used was surely a sufficient compensation for any expense in making them so large that a man could walk erect instead of being obliged to crawl on his hands and knees.

On one occasion he (Mr. Rigg) went down a coal pit; the men seemed only anxious to show the effects of the fire-damp by holding up their safety lamps against certain "blowers," and having their light obscured or put out altogether. Under such a system as Mr. André had recommended it would have been rather more comfortable. Mr. André said that the exit should be twice the size of the intake, but he (Mr. Rigg) supposed that such a statement applied only to the plenum system, for he could hardly imagine such an increase of size would be necessary in the vacuum system, where the velocity of the air when leaving would be so much greater than that of the air entering; but in the plenum system no doubt the outlet should be

twice as large as the intake. Mr. André's plans were most interesting and important, and persons were far too apt to make small openings for ventilation instead of large ones, not only in coal mines, but wherever ventilation was required.

Mr. Druitt Halpin said he believed that mining engineers reckoned that they did a pretty good duty on the average in the natural system of ventilation, if with a consumption of 50 lbs. of coal an hour they dislodged a quantity of air represented by 33,000 foot-pounds per minute in one horse-power. On the mechanical system, in some of the best-arranged methods, they worked at about 10 lbs. per horse-power per hour. With good Guibal fans, which had lately been introduced from Belgium, they got a duty out of the fan of 40 or 45 per cent. of the power put into the engine. They used 8 or 10 lbs. of coal per horse-power per hour. It was therefore a matter of calculation what should be laid out in the mechanical arrangements. Coal at the

point of production was often so cheap as sometimes not to require to be very accurately considered. The mechanical method was the most certain of the two, and was gradually gaining ground. The great advantage of the Guibal system of fans was that the fans did not allow a mass of mechanical power to pass them and come away without being utilized. A large duty was got out of the fans by gradually diminishing the velocity of the issuing air, and letting the whole body of the gases go away at an almost nominal velocity. A movable shutter worked up and down to regulate it.

Mr. André, in replying upon the discussion, observed that with regard to Mr. Baldwin Latham's remarks about the old and new mines, he (Mr. André) thought that they were quite in accordance with his remarks in the paper, because he proportioned the quantity of air to the area exposed, and therefore in an old mine, where there was a much larger area exposed than in a new one, more air would have to pass through. With

respect to the goaf, or the portion worked away, as the pillars were worked away, air-passages would still be left through it. It would be altogether wrong to leave it with pent-up accumulations of gas, so as to make it anything like a gas holder. He knew that was sometimes done, but it was a very dangerous practice. Passages must be left clear to carry away all the gases which were given off in the goaf. Goaves were very dangerous places, and many explosions had resulted from proper care not being taken with them. The air ought to be passed from the goaf directly into the return passages.

Mechanical ventilation was certainly coming more into use. In some respects it was preferable to the furnace, but he was not altogether in favor of it. It was entirely dependent on the fan, and if the machinery broke down the ventilation was stopped at once through the whole mine. In the case of furnace ventilation, it would be a difficult thing to put out the fire all at once, and if that was done

the shaft would be still hot, and the ventilation would be carried on for some considerable time; that was a great advantage. It was true that the engine burnt less coal than the furnace, but the coal had to be brought up to the engine before it could be burned, and though the cost of bringing it up was not much, still it was something. He believed that the furnace system, taking it altogether, was better than the other. With regard to the plenum system, he did not think that that would do at all. The vacuum system was the only one to be adopted, and in that case he certainly thought that the return passages would require a large area just the same, because when the air passed down the downcast, it was at a certain temperature, and had a certain volume, and in passing through the workings it got considerably heated and expanded. He believed that an additional area would be required, whichever way the air was expelled.

A remark had been made about the

proportion of the intake to the outlet being as 1 to 2. When he (Mr. André) spoke of the factor of safety he was not referring to the size of the return passages. The factor of safety referred to the quantity of air passed through the whole mine or a whole district. The sectional area of the returns compared to that of the intake should be as 2 to 1. The stalls or passages must not be considered to be full of impurities. The impurities were gradually given off, and there was not such a vast volume to carry away. The gases exuded all over the surface in small proportions relatively to the quantity of air to be passed through the mine, and it would be sufficient to make the return passages twice as large as the intake.

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